



How Does Uncertainty in Input Parameters Affect PV Performance Model Output

Cliff Hansen, Joshua Stein and Steven Miller
Sandia National Laboratories
Albuquerque, New Mexico, USA

PV Performance Modeling Workshop
September 22-23, 2010

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy's National Nuclear Security Administration
under contract DE-AC04-94AL85000.





Problem Statement

- **Uncertainties in PV system performance models impact business decisions**
 - Technology choices
 - Project cost and financing
- **Performance has typically been estimated (using several models) without much attention to quantifying uncertainties**
- **Identifying model sensitivities helps focus efforts to validate models and to reduce uncertainties**



Objective and Methods

- **Demonstrate assessment of the effect of parameter uncertainties on model output**
 - Use Sandia PV Array Performance Model ('King model')
 - Consider effect on total annual DC energy production
- **Analysis for three locations: Phoenix, Alamosa, Detroit**
- **Fixed weather year and single PV module**
 - SunPower SPR210-WHT module
- **Sampling-based approach**
 - Assign uncertainty ranges to model inputs
 - Generate sample
 - For each sample element compute model results
 - Investigate correlations between inputs and model output
- **Study of model sensitivity (of a single model) rather than prediction of system performance**

Sandia Array Performance Model

This series of calculations determines the power at maximum-power point, P_{mp} , for the particular module defined by the module parameters input.

Reference Sandia Report SAND2004-3535, *Photovoltaic Array Performance Model* (King, Boyson, and Kratochvill) for a detailed discussion of the parameters and empirical equations used for calculating the power at maximum-power point.

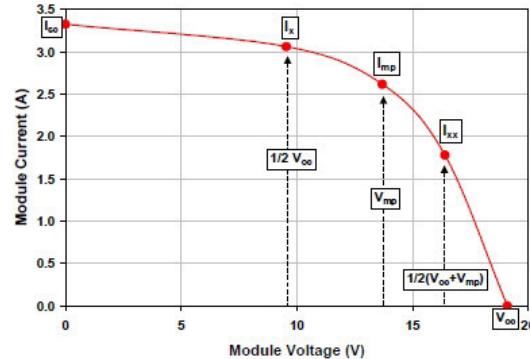
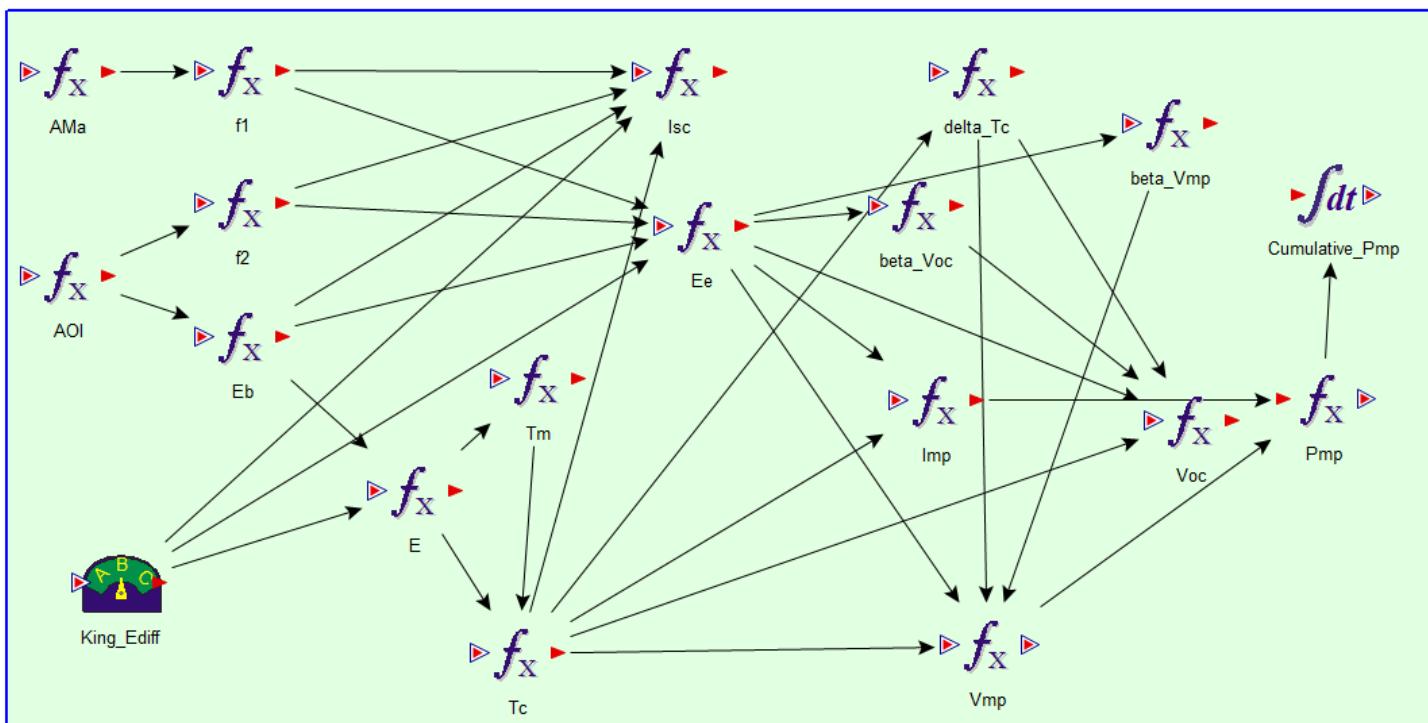


Illustration of a module I-V curve showing the five points on the curve that are provided by the Sandia performance model.
(Source: SAND2004-3535, *Photovoltaic Array Performance Model* (King, Boyson, and Kratochvill).



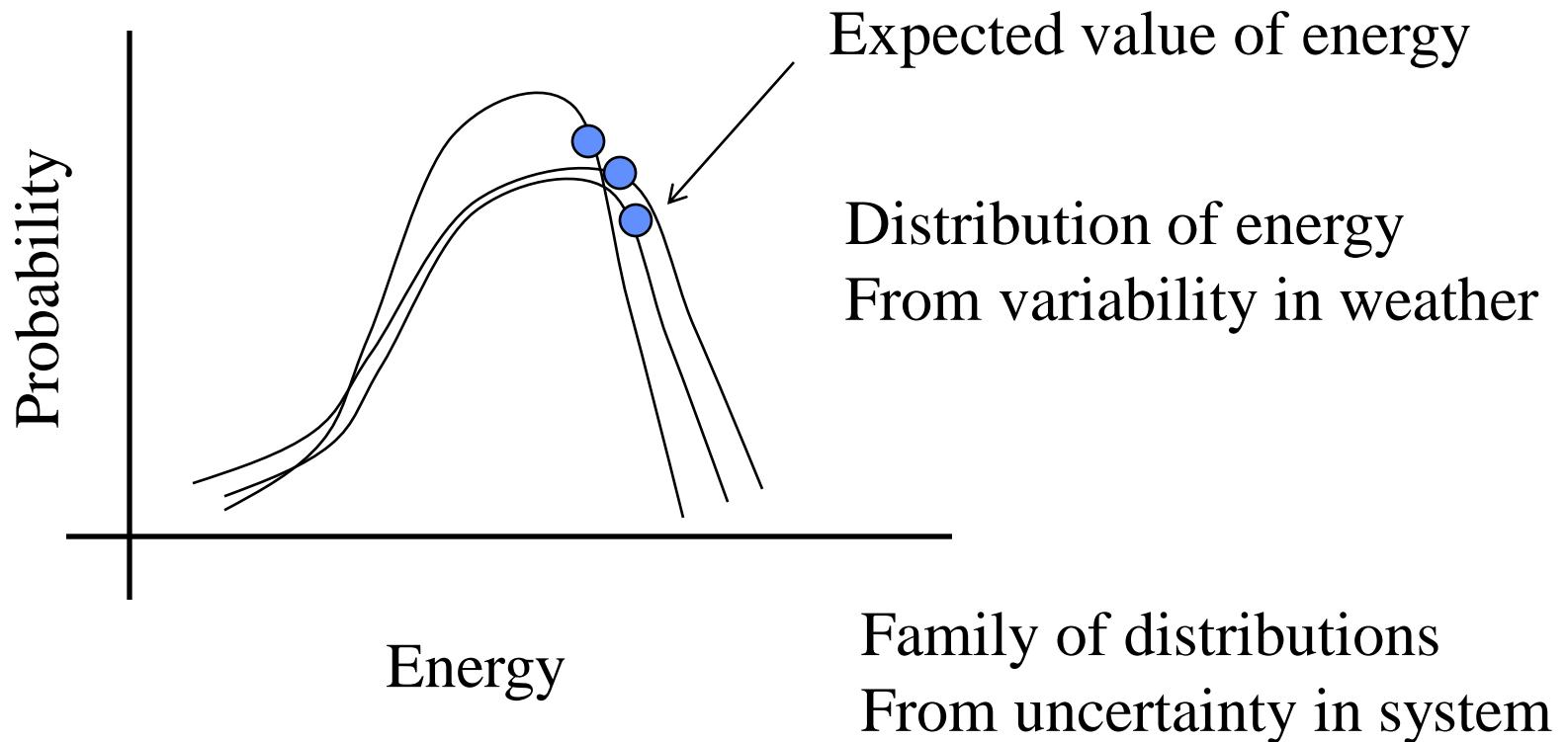


Types of Inputs and Uncertainties

- **Uncertainty: Parameters assumed to have fixed but imperfectly known values**
 - Parameters related to system performance
 - E.g. Error in estimates of P_{MP} , V_{MP}
 - Parameters related to empirical model approximations
 - E.g. Coefficients in equation relating V_{MP} to effective irradiance
- **Variability: Parameters characterizing inherently variable quantities**
 - Global horizontal irradiance, temperature, wind speed
- **Variability parameters fixed in this analysis to isolate effects of uncertain parameters**



Structure for estimating probability of return





Uncertain Parameters

- Array orientation error (tilt and azimuth): Normal {mean = 0, std = 1 deg}
- Albedo uncertainty: Uniform [0.1 – 0.3]
- P_{mp} error (assumed 210 W): Uniform [-5% – 5%]
- V_{mp} error: Uniform [-0.1 – 0.1 V]
- I_{mp} : Calculated
- alpha_{lmp} relative error: Empirical {min = 0.5, median = 1, max = 2}
- BetaVmp relative error: Uniform [-5% – 5%]
- C0 relative error (coeff in I_{MP} – Eff. Irrad.): Uniform [-2% – 2%]
- C2 relative error (coeff in V_{MP} – Eff. Irrad.): Uniform [-2% – 2%]
- C3 relative error (coeff in V_{MP} – Eff. Irrad.): Uniform [-2% – 2%]
- a absolute error (coeff in mod. temp approximation): Uniform [-0.05 – 0.05]
- b relative error: (coeff in mod. temp approximation): Uniform [-20% – 20%]
- AM correction factor error: Uniform [-5% – 5%]
- AOI correction factor error: Uniform [-5% – 5%]
- Diffuse POA model: Discrete [H&D, Reindl, Perez]
- Perez coefficients: Discrete [1988 or 1990]



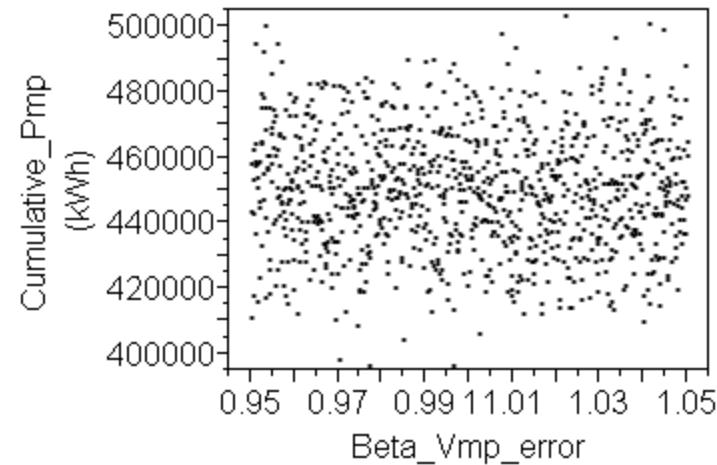
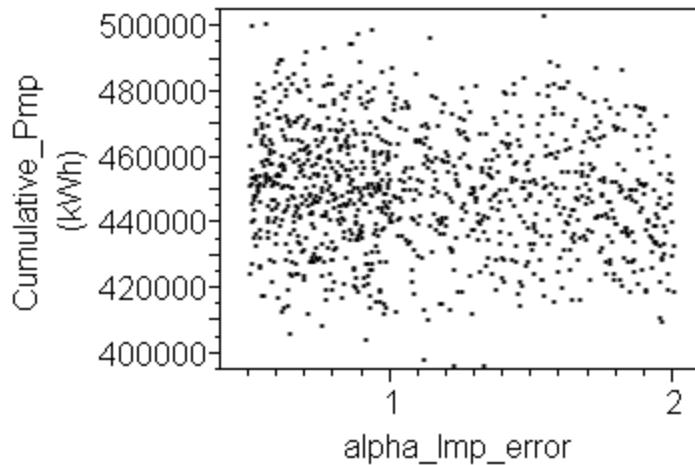
Variable Parameters

- **Use fixed meteorological years**
 - Phoenix, AZ (TMY2 weather)
 - Alamosa, CO (TMY2 weather)
 - Similar irradiance to Phoenix, colder temperature
 - Detroit, MI (TMY2 weather)
 - Diffuse climate
- **Follow-on study:**
 - Synthetic weather file designed to examine combinations of:
 - GHI [1100, 1000, 800, 600, 400, and 200 W/m²]
 - Diffuse fraction [0.1, 0.3, 0.5, 0.7, 0.9, and 1]
 - Air Temp [-20, -10, 0, 10, 20, and 30 deg C]
 - Wind Speed [0, 2, 4, and 6 m/s]

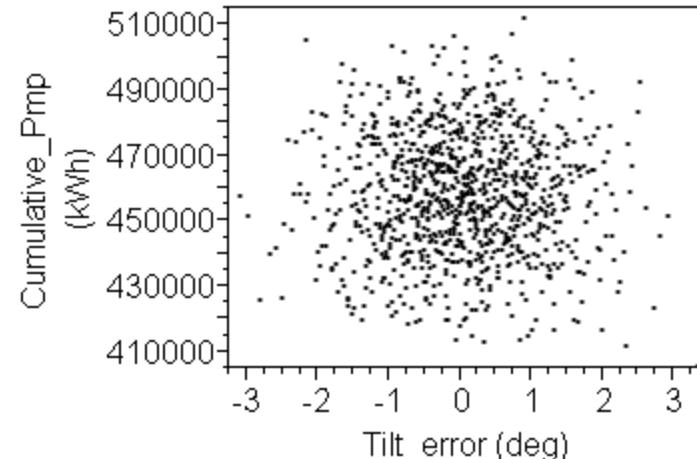
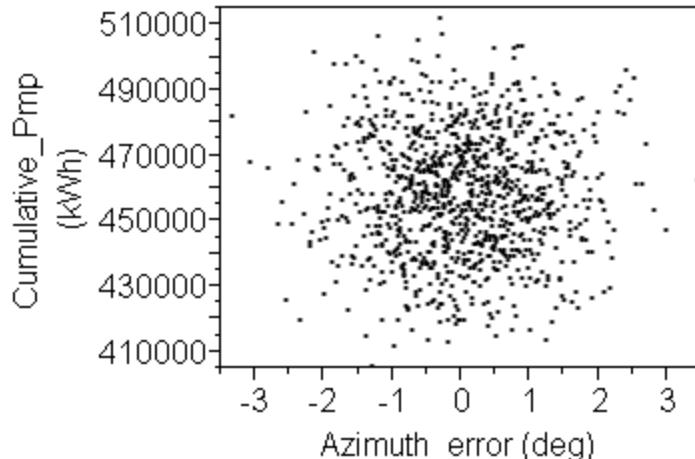


Phoenix Results

- Some uncertainties are not influential



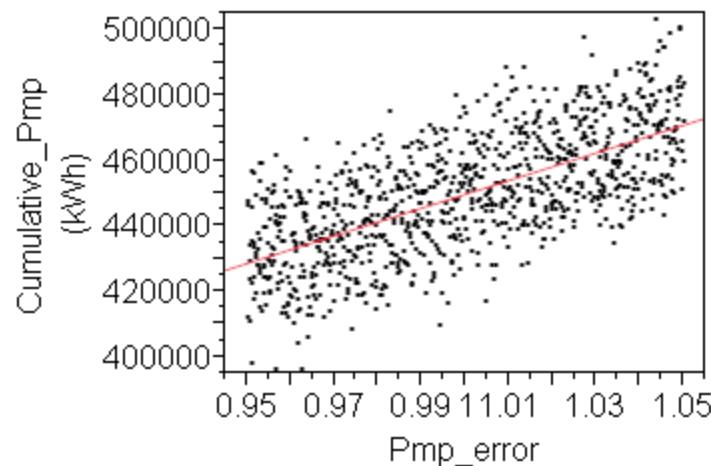
- Some uncertainties have weak, nonlinear effects





Phoenix Results

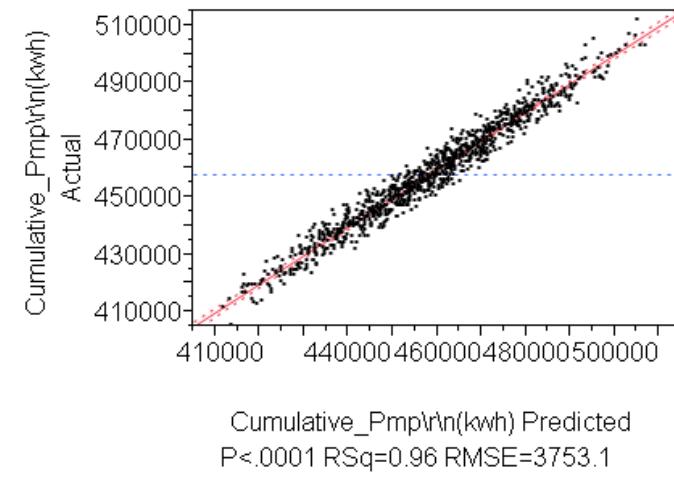
- Some uncertainties have strong effects

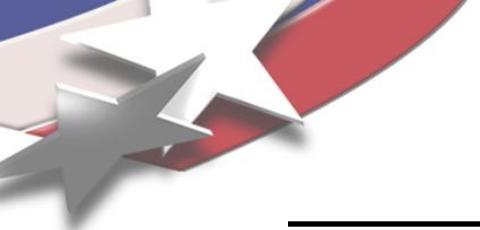


- Sampling based approach allows for regressions between input and output
- Stepwise regression ranks parameters from most influential to less influential

Stepwise Regression (Phoenix)

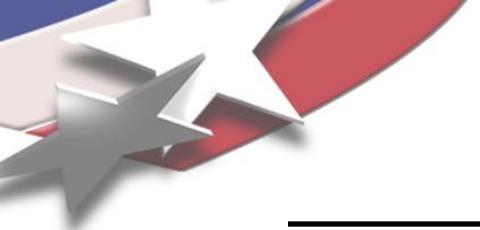
Step	Parameter	RSquare	Effect
1	Pmp_error	0.4442	+
2	AOI_Factor(f2)	0.7318	+
3	AM_factor (f1)	0.8598	+
4	C0_error	0.9295	+
5	Diffuse_Rad_Model	0.9423	+
6	Ground_reflectivity	0.9531	+
7	alpha_Imp_error	0.9590	-
8	Beta_Vmp_error	0.9637	-
9	a_error	0.9668	-
10	b_error	0.9694	+
11	Perez_F_coeffs	0.9707	+
12	Vmpo_error (V)	0.9716	-
13	Array_tilt_meas_error (deg)	0.9718	-





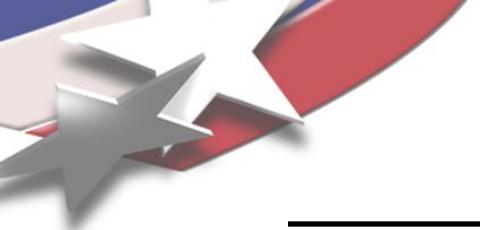
Comparison Among Locations

	Alamosa		Phoenix		Detroit	
Step	Parameter	R ²	Parameter	R ²	Parameter	R ²
1	Pmp_error	0.4216	Pmp_error	0.4442	Pmp_error	0.5061
2	AOI_factor(f2)	0.6993	AOI_Factor(f2)	0.7318	AOI_Factor(f2)	0.6823
3	AM_factor(f1)	0.8671	AM_factor (f1)	0.8598	AM_factor (f1)	0.7954
4	C0_error	0.9354	C0_error	0.9295	C0_error	0.8749
5	Diffuse_Rad_Model	0.9552	Diffuse_Rad_Model	0.9423	Diffuse_Rad_Model	0.9298
6	Ground_reflectivity	0.9694	Ground_reflectivity	0.9531	Ground_reflectivity	0.9603
7	a_error	0.9718	alpha_Img_error	0.9590	b_error	0.9632
8	b_error	0.9741	Beta_Vmp_error	0.9637	Array_tilt_meas_error (deg)	0.9659
9	Vmpo_error (V)	0.975	a_error	0.9668	a_error	0.9673
10	Perez_F_coeffs	0.9757	b_error	0.9694	Vmpo_error (V)	0.9685
11	Azimuth_meas_error (deg)	0.9761	Perez_F_coeffs	0.9707	Perez_F_coeffs	0.9692
12	Beta_Vmp_error	0.9763	Vmpo_error (V)	0.9716	Beta_Vmp_error	0.9694
13	C2_error	0.9763	Array_tilt_meas_error (deg)	0.9718	Azimuth_meas_error (deg)	0.9695



Summary

- PV system performance model amenable to uncertainty and sensitivity analysis
 - Sampling-based approach efficient
- For the example used, most significant uncertainties are:
 - P_{MP}
 - AOI correction factor
 - AM correction factor
 - C0 coefficient (relating I_{MP} to effective irradiance)
- Similar findings for different locations
- Results used fixed weather at each location
 - Relative effect of variation in irradiance not determined



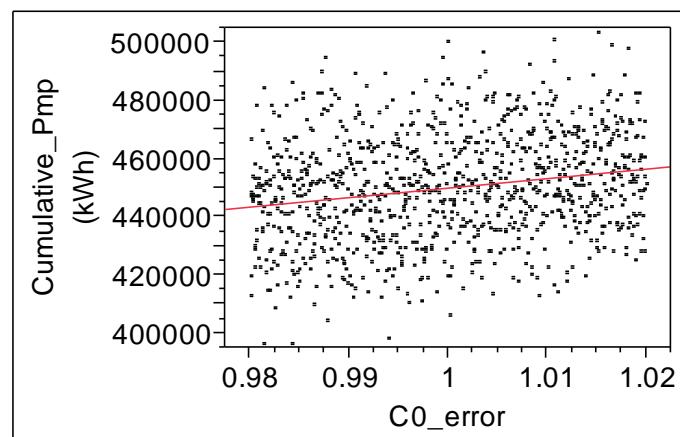
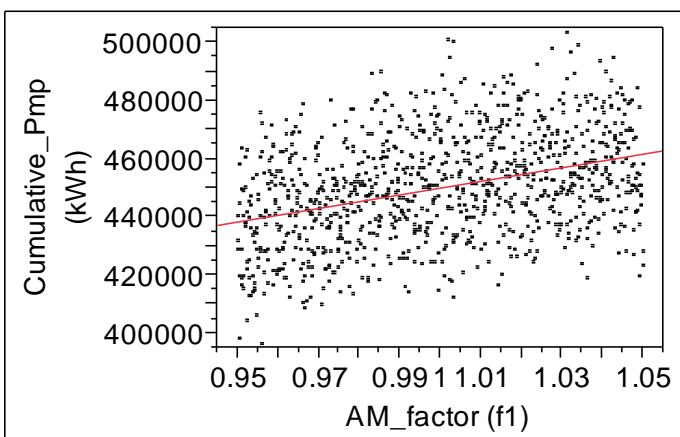
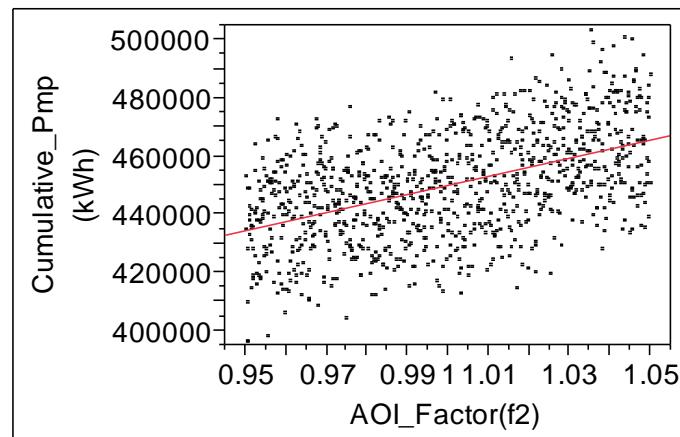
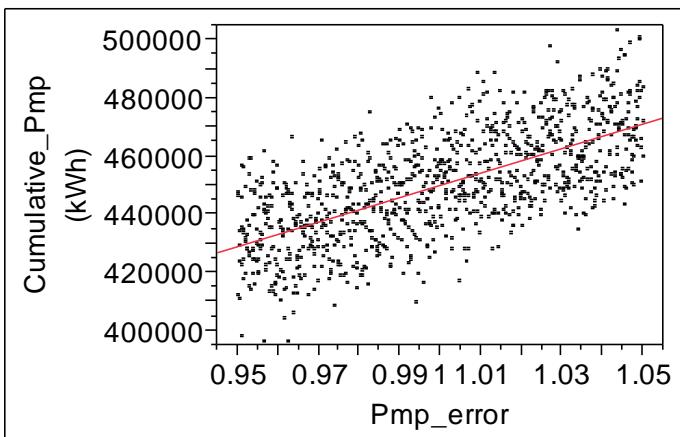
Conclusions

- **Sensitivity studies can inform model validation**
 - Uncertainty and sensitivity analyses are investigations of the model
 - Model sensitivities can guide model validation efforts
 - Guide data collection priorities
 - Experimental design considerations
 - Location
 - Technology
 - Consistent metrology
 - High quality measured performance data from diverse systems is still needed for model validation
- **Sensitivity studies can aid in model development**
 - Indicates processes important to uncertainty in model output
- **Findings about model sensitivities may not apply to other systems or where model is a poor representation**

BACKUP

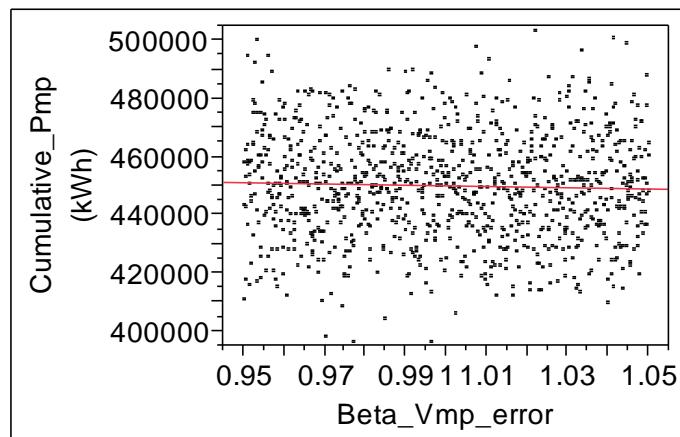
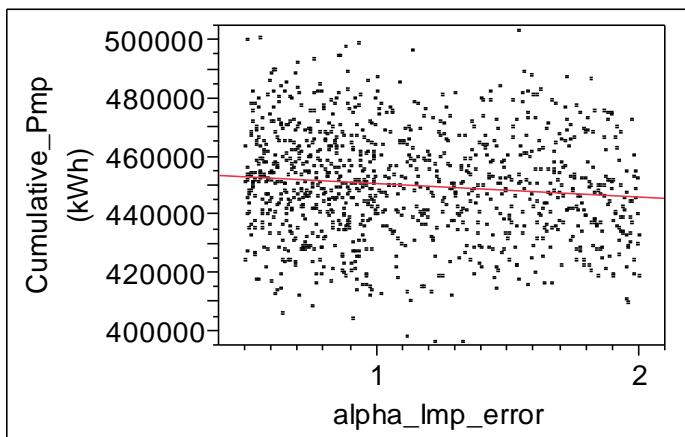
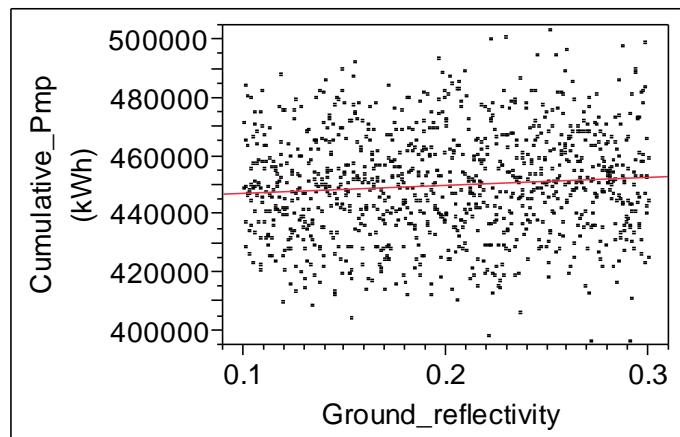
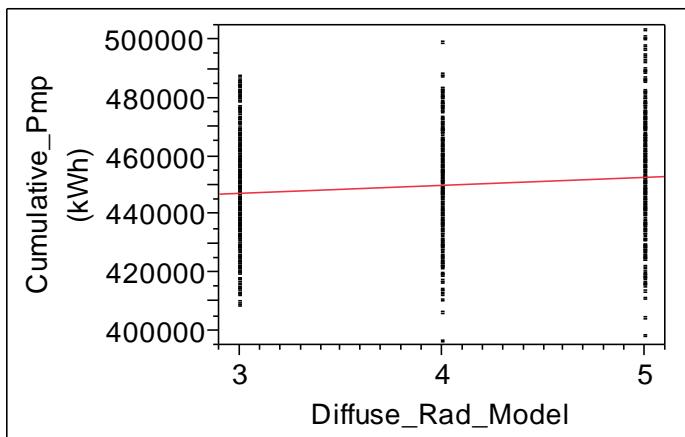


Backup: Phoenix results (1 of 3)





Backup: Phoenix results (2 of 3)





Backup: Phoenix results (3 of 3)

